THE ADSORPTION OF FATTY ACIDS ON CARBON BLACK

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SUMMARY

The author's experimental data are presented and discussed for the adsorption of three fatty acids of equal chain length but varying in degree of saturation on four different carbon black surfaces.

All of the carbon black samples were made from the same raw material with the surfaces changed by subjecting portions to different final treatment to vary the quantity and type of adsorbed gaseous matter.

The devolatilized carbon surfaces were found to adsorb larger amounts of all three acids per square meter of surface area than the oxidized surfaces, and the saturated acid was found to obey Langmuir's adsorption isotherm whereas the unsaturated acids followed more nearly the Freundlich relation. The data are discussed on the basis of monolayer adsorption for the Langmuir curves and multilayer adsorption for the Freundlich isotherms resulting from the higher attractive forces of the carbon black for the unsaturated bonds.

INTRODUCTION

The many volumes of work done in the field of adsorption have stood as more or less isolated pieces of data due to the wide variety of adsorbents and adsorbates used until recent thermodynamic treatments have correlated the data obtained in the most simple gas - solid systems. In spite of the lack of theoretical knowledge of the more complex liquid - solid systems, their use in industry for purifying various solution mixtures is becoming increasingly more important.

For many years, the rubber industry has supported research programs to determine the action of "fillers" in rubber compounds. Since carbon black is by far the most widely used of these "fillers", the chemical and physical forces existing between carbon black particles and rubber molecules is of the greatest importance in the production of a product having the desired characteristics. To study these forces, simpler adsorption systems have been investigated using carbon black as the solid phase.

In this study, it was desired to determine the effect of the degree of unsaturation of the adsorbate and the chemical and physical properties of the adsorbent surface on the adsorption isotherms. For this purpose, three fatty acids of identical chain length but varying in degree of unsaturation were adsorbed from solution on carbon black surfaces whose chemical and physical nature were known.

MATERIALS USED AND METHOD OF DETERMINATION OF ADSORPTION VALUES

In this investigation, three fatty acids of equal chain length were adsorbed from hexane solution on carbon black. Commercial grades of stearic and oleic acid were obtained from the Eastman Kodak Co., and reagent grade linoleic acid was supplied by the Research Chemical Co. The hexane used is a commercially available close boiling range product* of the American Mineral Spirits Co.

The Research and Development Laboratories of the Godfrey L. Cabot Co. prepared and analyzed the four carbon black samples used. These samples (referred to by number throughout this paper) were prepared as follows:

Sample 1. Commercially available untreated channel black.

Sample 2. Channel black tumbled in a rotary kiln at 900°F. in the presence of air for approximately 90 minutes.

Sample 3. Channel black devolatilized by blowing a stream of nitrogen through a stationary bed of the black maintained at 2300°F.

Sample 4. Channel black, first oxidized as in the preparation of sample No. 2, then devolatilized as in the preparation of sample No. 3.

These samples were analyzed** for both surface area and volatile content. The surface area determinations were made using the nitrogen

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* See Appendix, Table I, for boiling range.

** See Appendix, Table II, for analyses.

adsorption method of Brunauer, Emmet, and Teller[1] and the volatile content determined by the usual A.S.T.M. method for coke and coal[2].

Before making the experimental determinations that were necessary to construct the adsorption isotherms for the various acids and carbon samples, preliminary experiments were performed to determine whether or not the carbon surface was contaminated with any substance which might be dissolved by the solvent, and interfere with the determination of the fatty acids. For this purpose, 1 gm. portions of each carbon black sample were weighed into 60 ml. conical form weighing bottles, and 50 ml. of hexane was added to each bottle. After shaking and allowing the bottles to stand overnight, 25 ml. portions of the supernatant liquids were withdrawn, transferred to weighed dishes, and evaporated to dryness. A check weighing of these dishes after drying indicated that no residue was left.

The determination of a point on the adsorption isotherm was made in a similar manner. An approximately 2 gm. portion of the carbon was weighed to the nearest milligram into a 60 ml. glass stoppered weighing bottle, and 10 ml. of hexane added to moisten the carbon and displace the occluded air. Then, 50 ml. of a stock solution of the fatty acid

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1 Brunaur, S., Emmett, P. H., and Teller, E., "Adsorption of Gases in Multimolecular Layers", Journal of the American Chemical Society, Vol. 60, 1938, pp. 309.

2 American Society for Testing Materials, A.S.T.M. Standards on Coal and Coke, Philadelphia, Pa., August 1947, pp. 22-23.

dissolved in hexane was transferred to the bottle by means of a volumetric pipette, and the bottle stoppered and reweighed to the nearest milligram. Stock solutions were made up by weight, and their concentrations checked by titration. After weighing, the bottle was swirled to bring the fluffy carbon into contact with all of the solution, and was then placed in a constant temperature water bath maintained at $30 \pm 1^{\circ}C$. The bottle was then swirled intermittently five or six times for the next hour, and allowed to stand in the bath overnight.

The following day, the bottle was reweighed, and 25 ml. of the supernatent liquid was withdrawn and transferred to a small Erlenmeyer flask. This liquid was evaporated to near dryness over a steam bath, and the fatty acid residue was dissolved in approximately 25 ml. of previously neutralized methyl alcohol. The alcohol solution was heated to the boiling point to assure solution of the acid, and titrated with a standard alcoholic sodium hydroxide solution to a near phenolphthalein end point. Since several milliliters of indicator solution were necessary to produce a satisfactory end point in the alcoholic solution, 25 ml. of distilled water was added when nearly all of the acid had been converted to the sodium salt. The solution was then reheated to boiling, and the titration completed. This procedure gave a satisfactory end point with two or three drops of phenolphthalein solution.

Taking into account the evaporation of the solvent during the period the adsorption was taking place, (this was done by loss in weight of the bottle during this period) the total quantity of acid in the solution was calculated, and the adsorbed acid obtained by difference.

Desorption values were also determined by replacing the solution

withdrawn for the first analysis with pure solvent, and then, the same procedure followed as was used in the determination of the adsorbed acid. Since the error involved in determining the acid removed for analysis in the first determination is included in the calculation of the adsorbed acid for a desorption value, the latter necessarily contains twice as much error. For this reason, more weight has been given to the adsorption values in drawing the isotherm curves presented in Figures I through VIII. The desorption points have been marked with a tail to distinguish them from the adsorption points on the graphs.

Equilibrium checks were not made for each system, but Cassidy[3] found that equilibrium was obtained in a very few minutes for the carbon, petroleum ether, fatty acid system. At first glance, the fact that the desorption points in almost all cases fall slightly above the curves would tend to cast doubt as to the actual attainment of equilibrium. However, this can be explained by the fact that small traces of the fatty acids were noticed around the tops of the glass stoppered bottles, indicating that in swirling, some of the liquid touched the ground glass joint and was carried to the top by capilary attraction, and whereas the loss in solvent was taken into account by weight loss, there was no way of calculating this loss of acid from the bottle. In the method of calculation used, this loss of acid would appear to be adsorbed acid.

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3 Cassidy, H.G., "Adsorption Analysis II: The Adsorption of Higher Fatty Acid", Journal of the American Chemical Society, Vol. 62, 1940, pp. 3073 - 3076.

DISCUSSION OF RESULTS

The results obtained by plotting the adsorption isotherms on the basis of grams of acid adsorbed per gram of carbon were too confused to allow any conclusions to be drawn. However, if the variable of surface area is eliminated by plotting these curves on the basis of a common surface area*, some interesting correlations and trends become apparent.

Since the curves for stearic acid appeared to be similar to Langmuir's adsorption isotherm[4],

$$\frac{x}{m} = \frac{abC}{1 + aC}$$

where $\frac{x}{m}$ is the weight of adsorbed acid per 100 square meters of carbon surface, C the concentration of the solution in equilibrium with the adsorbed phase, and a and b are constants, this type curve was fitted to the data for stearic acid, and the actual curves drawn through the experimental points are Langmuir curves using the constants in Table VI.

The curves for linoleic acid followed Freundlich's equation[4],

$$\frac{x}{m} = kC^{1/n}$$

where $\frac{x}{m}$ and C are the same as in the Langmuir equation, and k and n are the Freundlich constants. The Freundlich curves, using the

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* See Appendix, Figures IV, V, and VI.

4 Lewis, W. K., Squires, S. M., and Broughton, G., Industrial Chemistry of Colloidal and Amorphous Materials, New York, The MacMillan Co., 1942, pp. 90.

constants also recorded in Table VI, have been drawn through these experimental points. Freundlich curves also best fitted the oleic acid adsorbed on devolatilized carbons, but Longmuir curves best expressed the adsorption of oleic acid on the oxidized and untreated carbon surface.

In all cases, the two devolatilized carbons (samples 3 and 4) adsorbed the same quantities of each acid. The oxidized carbon surface (sample 2) adsorbed less of the three fatty acids than any of the other three carbon samples. The untreated carbon black (sample 1) containing only the volatile substances adsorbed from the combustion gases surrounding it at the time of its manufacture, varied widely in its adsorption of the three acids (Figs. IV, V & VI). This carbon adsorbed about the same quantity of stearic acid as carbon 2 (Fig. IV), and slightly more oleic acid than carbon 2 (Fig. V). When the adsorbed acid contained still another double bond, however, carbon 1 adsorbed the same quantity as the devolatilized carbon samples (Fig. VI).

It is also interesting to note that the devolatilized carbon blacks adsorb a greater weight of stearic acid than oleic or linoleic acid at the point that the isotherms begin to flatten out (Figs. IV, V and VI). The stearic acid curve (Fig. IV), however, remains essentially flat after reaching this point, whereas, the isotherms for the two unsaturated acids (Figs. V and VI) continue to rise as the solution concentration increases.

From these two observations, it would appear that the forces of attraction between these carbon surfaces and the fatty acids increases as the degree of unsaturation of the acids increases. Although heat

of adsorption data would be necessary to confirm this supposition, the data available can best be explained on this basis.

Kimball[5] has shown that the longest saturated hydrocarbon molecule that will be totally adsorbed on a mercury surface (i.e., touch the surface over its entire length) is heptane. The unpublished data of Beebe[6] indicates that pentane is the longest molecule that is totally adsorbed on carbon black. Molecules of greater length are believed to be adsorbed only in part, with an end or possibly both ends projecting away from the carbon. If this be the case in the adsorption of the fatty acids, and the assumption that the unsaturated bonds are more strongly adsorbed is valid, the unsaturated acids might well be expected to occupy a larger space on the carbon per molecule. This would help to explain why the actual adsorption is less for the unsaturated acids at the point at which the curves begin to flatten, (monolayer adsorption) but since the surface is not completely covered with acid molecules, but partially by the solvent as well, this effect would not be conclusive unless the quantity of hexane molecules adsorbed by the carbon was the same in both cases. Recent work by Halsey[7] in deriving a theoretical energy expression for multilayer adsorption,

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5 Kimball, G., and Rideal, E. K., "The Adsorption of Vapors on Mercury", Proceedings of the Royal Society", Vol. 187A, 1946, pp. 53 - 73.

6 Beebe, R.L., Kinston, G.A., Polly, M. H. and Smith, W. R., "Heat of Adsorption of Hydrocarbons on Carbon Black", Submitted for publication to Journal of the American Chemical Society.

7 Halsey, G.M., A manuscript of paper presented at Lehigh University, Symposium on Adsorption, May 1947. Submitted for publication to Journal of Chemical Physics.

(analogous to the Freundlich equation) supports the belief that multilayer adsorption takes place when the adsorption curves follow the Freundlich expression, and explains the continued rise in the case of the greater attraction forces between unsaturated acids and devolatilized carbon blacks. Where the smaller forces exist between the saturated acids and the devolatilized carbon blacks, the second layer would not be so likely to form, and this is exhibited by the Langmuir type curves found for stearic acid.

Two effects seem to limit the adsorption of the fatty acids by the oxidized carbon surface. The first is the physical effect of a surface already crowded with adsorbed volatile material. The actual weight of volatile constituents adsorbed on the oxidized carbon was from four to ten times the weight of the acid adsorbed, whereas the volatile material on the devolatilized carbons was only one-third to one-half the weight of the adsorbed acids. In addition to this physical effect, Smith and Schaeffer[8] have found that oxygen-treated carbon surfaces have a lower pH than devolatilized carbons. Since the oxygen-treated surfaces have a pH lying in the acid zone, and the devolatilized surfaces have a pH value that is alkaline, the forces of chemical attraction for the carboxyl group of the fatty acid would not be as strong on the acid carbon surface.

Although these effects greatly hinder the adsorption of the fatty acids, they do not completely mask the attractive force for the

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8 Smith, [illegible]. R., and Schaeffer, W. D., "Physics and Chemistry Carbon Surfaces", to be read at 115th meeting of the American Chemical Society at San Francisco, 1949.

unsaturated bonds of linoleic acid, as evidenced by the greater adsorption of this acid, and the change from Langmuir to Freundlich type curves as the degree of unsaturation increases. This is also shown by the untreated carbon, although the physical and chemical hindrances do not dominate the adsorption so prominently.

CONCLUSIONS

From the data and discussion, the following conclusions have been drawn:

1. The adsorption of stearic acid on carbon black give isotherms of the Langmuir type, whereas linoleic acid gave Freundlich type adsorption isotherms.

2. The devolatilized carbon samples adsorbed larger amounts of all three acids per square meter of surface area than the oxidized surface.

3. The forces of attraction are greater between the carbon surfaces and the unsaturated acids than between the carbon surfaces and the saturated acid. These forces become more pronounced as the degree of unsaturation is increased.

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CALCULATIONS

(These calculations are for Stearic acid adsorbed on carbon sample No. 1 point No. 1)

Wt. of Bottle	42.397 gm
Wt. of Bottle and Carbon	44.401 gm
Wt. of Carbon	2.004

Volume of hexane added to carbon	10.00 ml.
Volume of acid solution added	50.00 ml.
Total volume of starting solution	60.00 ml.

Concentration of Stearic acid solution in hexane 1.004 gm./l.

$$\text{Stearic acid added to carbon in solution} = \frac{1.004 \times 50}{1000} = 0.0502 \text{ gm.}$$

Wt. of bottle, carbon and starting solution	85.259 gm.
Wt. of bottle, carbon and solution after adsorption	84.131 gm.
Wt. of hexane evaporated	1.128 gm.

Density of hexane 0.660 gm./ml.[9]

$$\text{Volume of hexane evaporated} = \frac{1.128}{0.660} = 1.71 \text{ ml.}$$

Volume of solution at equilibrium = 60 - 1.71 = 58.29

Equilibrium concentration of solution 0.612 gm./l.

$$\text{Wt. of Stearic acid in equilibrium solution} = \frac{0.612 \times 58.29}{1000} = 0.0357 \text{ gm.}$$

Wt. of adsorbed Stearic acid = 0.0502 - 0.0357 = 0.0145 gm.

$$\text{Wt. of adsorbed acid/gm. carbon} = \frac{0.0145}{2.004} = 0.0072 \text{ gm.}$$

Square meters of surface/gm. of carbon = 101

$$\text{Wt. of adsorbed acid/100 square meters of surface} = \frac{0.0072 \times 100}{101}$$

$$= 0.0071 \text{ gm.}$$

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9 Hodgman, C. D., Editor-in-Chief, Handbook of Chemistry and Physics, Thirtieth Edition, Cleveland, Ohio, Chemical Rubber Publishing Co., 1948, pp. 850 - 851.

For desorption point, after removing the 25 ml. of solution for the first analysis 25 ml. of hexane was added and the bottle reweighed.

Wt. of bottle, carbon, and starting solution 84.077 gm.

Wt. of bottle, carbon, and solution after adsorption 82.780 gm.

Wt. of hexane evaporated 1.297 gm.

Volume of hexane evaporated = $\frac{1.297}{0.660}$ = 1.98 ml.

Volume of solution at equilibrium = 58.29 - 1.98 = 56.31 ml.

Equilibrium concentration of solution = 0.3520 gm./l.

Wt. of Stearic acid in equilibrium solution = $\frac{0.352 \times 56.31}{1000}$ = 0.0198 gm.

Wt. of Stearic acid removed in 25 ml. taken for previous analysis = 0.0153 gm.

Wt. of adsorbed Stearic acid = 0.0502 - 0.0198 - 0.0153 = 0.0151 gm.

Wt. of adsorbed acid/gm. carbon = $\frac{0.0151}{2.004}$ = 0.0075 gm.

Wt. of adsorbed acid/100 square meters of surface = $\frac{0.0075 \times 100}{101}$

= 0.0074 gm.

TABLE I: Boiling Range of Hexane

Barometric pressure 739.5 mm. at 30°C.
Temperature correction for barometric pressure + 0.80°C.

% Distilled	Observed temp. °C. Run 1	Run 2	Corrected temp. °C Run 1	Run 2
0	67.5	67.5	68.3	68.3
5	68.0	68.0	68.8	68.8
10	68.0	68.0	68.8	68.8
15	68.0	68.0	68.8	68.8
20	68.0	68.1	68.8	68.9
25	68.1	68.2	68.9	69.0
30	68.2	68.2	69.0	69.0
35	68.2	68.2	69.0	69.0
40	68.2	68.2	69.0	69.0
45	68.3	68.3	69.1	69.1
50	68.4	68.4	69.2	69.2
55	68.4	68.4	69.2	69.2
60	68.4	68.4	69.2	69.2
65	68.5	68.5	69.3	69.3
70	68.6	68.6	69.4	69.4
75	68.7	68.7	69.5	69.5
80	68.8	68.8	69.6	69.6
85	68.9	68.9	69.7	69.7
90	69.0	69.0	69.8	69.8
95	69.1	69.1	69.9	69.9
end	70.0	70.0	70.8	70.8

TABLE II: Analyses of Carbon Samples (analyses by Research and Development Laboratory of Godfrey L. Cabot, Inc.)

Carbon Sample	Volatile (%)	Surface Area (square meters/gm.)
1	6.2	101
2	11.8	191
3	1.0	131
4	1.8	164

TABLE III: Summary of Experimental and Calculated Data For Stearic Acid (Adsorption Points).

Carbon Sample	Wt. of Carbon (gm)	Vol.of Sol. at Equil. (ml)	Equil Conc. (gm/l)	Acid in Equil.Sol. (gm)	Acid Added in Starting Sol(gm)	Acid Ads. on Carbon (gm)	Acid Ads. per gm.C (gm)	Acid Ads.per 100 Meters^2 Carbon (gm)
1	2.004	58.29	0.612	0.0357	0.0502	0.0145	0.0072	0.0071
1	2.001	58.69	3.000	0.1761	0.2003	0.0242	0.0121	0.0120
1	2.006	58.18	4.800	0.2793	0.3001	0.0208	0.0104	0.0103
1	2.050	58.63	6.416	0.3762	0.4000	0.0238	0.0116	0.0115
1	2.000	58.93	8.164	0.4811	0.5003	0.0192	0.0096	0.0095
2	2.009	58.45	0.456	0.0267	0.0502	0.0235	0.0117	0.0061
2	2.044	58.03	2.844	0.1650	0.2003	0.0353	0.0173	0.0090
2	2.019	58.45	4.552	0.2661	0.3001	0.0340	0.0169	0.0089
2	2.000	58.96	6.156	0.3630	0.4000	0.0370	0.0185	0.0097
2	2.030	57.92	8.048	0.4661	0.5003	0.0342	0.0169	0.0089
3	2.000	58.55	0.328	0.0192	0.0502	0.0310	0.0155	0.0118
3	2.054	58.12	2.348	0.1365	0.2003	0.0638	0.0311	0.0238
3	2.036	58.15	3.992	0.2321	0.3001	0.0680	0.0333	0.0254
3	2.043	58.71	5.632	0.3307	0.4000	0.0693	0.0339	0.0259
3	2.011	58.01	7.472	0.4335	0.5003	0.0668	0.0332	0.0254
4	2.047	58.25	0.196	0.0114	0.0502	0.0388	0.0189	0.0115
4	2.016	57.78	2.164	0.1250	0.2003	0.0753	0.0374	0.0228
4	2.045	58.04	3.756	0.2180	0.3001	0.0821	0.0401	0.0245
4	2.016	56.99	5.452	0.3107	0.4000	0.0893	0.0442	0.0269
4	2.016	58.20	7.148	0.4160	0.5003	0.0843	0.0417	0.0254

TABLE III: (Cont'd) Summary of Experimental and Calculated Data for Stearic Acid (Desorption Points).

Carbon Sample	Wt. of Carbon (gm)	Vol.of Sol. at Equil. (ml)	Equil Conc. (gm/l)	Acid in Equil.Sol. (gm)	Acid Removed for Ist. Analysis(gm)	Acid Ads. on Carbon (gm)	Acid Ads. per gm.C (gm)	Acid Ads.per 100 Meters^2 Carbon (gm)
1	2.004	56.31	0.352	0.0198	0.0153	0.0151	0.0075	0.0074
1	2.001	56.17	1.772	0.0995	0.0750	0.0258	0.0129	0.0128
1	2.006	56.11	2.804	0.1573	0.1200	0.0228	0.0114	0.0113
1	2.050	56.12	3.768	0.2115	0.1604	0.0281	0.0137	0.0135
1	2.000	56.18	4.976	0.2739	0.2041	0.0223	0.0111	0.0110
2	2.009	57.24	0.260	0.0149	0.0114	0.0239	0.0119	0.0062
2	2.044	56.02	1.708	0.0957	0.0711	0.0335	0.0164	0.0086
2	2.019	56.40	2.712	0.1530	0.1138	0.0333	0.0165	0.0086
2	2.000	57.15	3.600	0.2057	0.1539	0.0404	0.0202	0.0106
2	2.030	56.15	4.708	0.2644	0.2012	0.0347	0.0171	0.0090
3	2.000	57.40	0.196	0.0113	0.0082	0.0307	0.0153	0.0117
3	2.054	56.17	1.448	0.0813	0.0587	0.0603	0.0294	0.0224
3	2.036	56.30	2.400	0.1351	0.0998	0.0652	0.0319	0.0244
3	2.043	57.09	3.340	0.1907	0.1408	0.0685	0.0336	0.0256
3	2.031	56.11	4.408	0.2473	0.1868	0.0662	0.0330	0.0250
4	2.047	56.35	0.092	0.0052	0.0049	0.0401	0.0195	0.0119
4	2.016	55.74	1.332	0.0743	0.0541	0.0719	0.0356	0.0218
4	2.045	56.06	2.268	0.1271	0.0939	0.0791	0.0386	0.0235
4	2.016	53.95	4.224	0.2279	0.1363	0.0810	0.0401	0.0245
4	2.016	55.24	3.248	0.1827	0.1787	0.0937	0.0464	0.0283

TABLE IV: Summary of Experimental and Calculated Data for Oleic Acid (Adsorption Points).

Carbon Sample	Wt. of Carbon (gm)	Vol. of Sol. at Equil. (ml)	Equil Conc. (gm/l)	Acid in Equil. Sol. (gm)	Acid Added in Starting Sol (gm)	Acid Ads. on Carbon (gm)	Acid Ads. per gm. C (gm)	Acid Ads. per 100 Meters² Carbon (gm)
1	2.006	58.65	0.644	0.0378	0.0523	0.0145	0.0072	0.0071
1	2.000	58.31	3.124	0.1822	0.2079	0.0257	0.0128	0.0127
1	2.000	58.35	4.692	0.2738	0.2999	0.0261	0.0130	0.0129
1	2.016	58.56	6.380	0.3736	0.4006	0.0270	0.0134	0.0133
2	2.001	58.10	0.488	0.0284	0.0523	0.0239	0.0119	0.0062
2	2.014	58.51	3.004	0.1699	0.2079	0.0380	0.0189	0.0099
2	2.018	58.39	4.472	0.2611	0.2999	0.0388	0.0193	0.0101
2	2.003	58.30	6.172	0.3598	0.4006	0.0408	0.0203	0.0106
3	2.006	58.31	0.488	0.0285	0.0523	0.0238	0.0118	0.0090
3	2.016	57.96	2.856	0.1655	0.2079	0.0424	0.0210	0.0160
3	2.022	57.60	4.388	0.2527	0.2999	0.0472	0.0233	0.0178
3	2.013	57.99	6.052	0.3510	0.4006	0.0496	0.0247	0.0189
3	2.014	57.81	8.068	0.4664	0.5209	0.0545	0.0271	0.0207
4	2.010	58.15	0.340	0.0198	0.0523	0.0325	0.0162	0.0099
4	2.036	58.04	2.600	0.1509	0.2079	0.0570	0.0280	0.0171
4	2.011	58.18	4.132	0.2404	0.2999	0.0595	0.0296	0.0181
4	2.009	58.16	5.896	0.3429	0.4006	0.0577	0.0287	0.0175
4	2.022	57.82	7.864	0.4512	0.5209	0.0697	0.0345	0.0210

TABLE IV: (Cont'd) Summary of Experimental and Calculated Data for Oleic Acid (Desorption Points).

Carbon Sample	Wt. of Carbon (gm)	Vol.of Sol. at Equil. (ml)	Equil Conc. (gm/l)	Acid in Equil.Sol. (gm)	Acid Removed for 1st. Analysis(gm)	Acid Ads. on Carbon (gm)	Acid Ads. per gm.C (gm)	Acid Ads.per 100 Meters^2 Carbon (gm)
1	2.006	55.45	0.340	0.0189	0.0161	0.0173	0.0086	0.0085
1	2.000	55.56	1.848	0.1027	0.0781	0.0271	0.0135	0.0134
1	2.000	55.55	2.760	0.1533	0.1173	0.0293	0.0146	0.0145
1	2.016	55.20	3.792	0.2093	0.1595	0.0318	0.0158	0.0156
2	2.001	55.37	0.256	0.0142	0.0122	0.0259	0.0129	0.0067
2	2.014	56.37	1.712	0.0965	0.0726	0.0388	0.0193	0.0101
2	2.018	55.66	2.624	0.1460	0.1118	0.0421	0.0208	0.0109
2	2.008	56.01	3.620	0.2028	0.1543	0.0435	0.0216	0.0113
3	2.006	56.00	0.268	0.0150	0.0122	0.0251	0.0125	0.0095
3	2.016	55.27	1.752	0.0968	0.0714	0.0397	0.0197	0.0150
3	2.022	54.56	2.648	0.1445	0.1097	0.0457	0.0226	0.0173
3	2.013	55.46	3.596	0.1994	0.1513	0.0499	0.0248	0.0189
3	2.014	55.16	4.848	0.2674	0.2017	0.0518	0.0258	0.0197
4	2.010	55.89	0.232	0.0130	0.0085	0.0308	0.0153	0.0093
4	2.036	55.77	1.580	0.0881	0.0650	0.0548	0.0269	0.0164
4	2.011	55.75	2.480	0.1383	0.1033	0.0583	0.0290	0.0177
4	2.009	55.81	3.352	0.1871	0.1474	0.0661	0.0329	0.0200
4	2.022	55.39	4.644	0.2572	0.1951	0.0686	0.0340	0.0207

TABLE V: Summary of Experimental and Calculated Data for Linoleic Acid (Adsorption Points).

Carbon Sample	Wt. of Carbon (gm)	Vol.of Sol. at Equil. (ml)	Equil Conc. (gm/l)	Acid in Equil.Sol. (gm)	Acid Added in Starting Sol (gm)	Acid Ads. on Carbon (gm)	Acid Ads. per gm.C (gm)	Acid Ads.per 100 Meters^2 Carbon (gm)
1	2.041	57.93	0.412	0.0239	0.0510	0.0271	0.0133	0.0132
1	2.009	57.55	2.872	0.1653	0.2028	0.0375	0.0187	0.0185
1	2.017	58.17	4.928	0.2867	0.3323	0.0456	0.0226	0.0224
1	2.013	57.59	6.284	0.3619	0.4100	0.0481	0.0239	0.0236
2	2.001	58.28	0.328	0.0191	0.0510	0.0319	0.0159	0.0083
2	2.005	58.43	2.648	0.1547	0.2028	0.0481	0.0240	0.0098
2	2.026	58.03	4.796	0.2783	0.3323	0.0540	0.0267	0.0118
2	2.034	57.95	6.124	0.3549	0.4100	0.0551	0.0271	0.0125
3	2.012	58.18	0.408	0.0237	0.0510	0.0273	0.0136	0.0104
3	2.012	58.08	2.660	0.1545	0.2028	0.0483	0.0240	0.0183
3	2.022	58.08	4.728	0.2746	0.3323	0.0577	0.0285	0.0218
3	2.009	57.79	6.060	0.3502	0.4100	0.0598	0.0298	0.0228
3	2.004	57.96	7.772	0.4505	0.5102	0.0597	0.0298	0.0228
4	2.010	58.19	0.236	0.0137	0.0510	0.0373	0.0186	0.0113
4	2.007	57.91	2.412	0.1397	0.2028	0.0631	0.0314	0.0192
4	2.013	58.40	4.504	0.2630	0.3323	0.0693	0.0344	0.0210
4	2.004	58.22	5.796	0.3374	0.4100	0.0726	0.0362	0.0220
4	2.020	56.82	7.460	0.4243	0.5102	0.0859	0.0425	0.0259

TABLE V: (Cont'd) Summary of Experimental and Calculated Data for Linoleic Acid (Desorption Points).

Carbon Sample	Wt. of Carbon (gm)	Vol.of Sol. at Equil. (ml)	Equil Conc. (gm/l)	Acid in Equil.Sol. (gm)	Acid Removed for 1st Analysis(gm)	Acid Ads. on Carbon (gm)	Acid Ads. per gm.C (gm)	Acid Ads.per 100 Meters^2 Carbon (gm)
1	2.041	56.36	0.236	0.0133	0.0128	0.0249	0.0122	0.0121
1	2.009	54.86	1.660	0.0911	0.0718	0.0399	0.0199	0.0197
1	2.017	56.07	2.884	0.1617	0.1232	0.0474	0.0235	0.0232
1	2.013	54.74	3.728	0.2041	0.1571	0.0488	0.0242	0.0239
2	2.001	56.09	0.160	0.0090	0.0082	0.0338	0.0169	0.0089
2	2.005	56.62	1.488	0.0843	0.0662	0.0523	0.0261	0.0137
2	2.026	55.48	2.792	0.1549	0.1199	0.0575	0.0284	0.0149
2	2.034	56.43	3.400	0.1919	0.1531	0.0650	0.0320	0.0168
3	2.012	55.80	0.212	0.0118	0.0102	0.0290	0.0144	0.0110
3	2.012	55.65	1.580	0.0879	0.0665	0.0484	0.0241	0.0184
3	2.022	56.25	2.792	0.1571	0.1182	0.0570	0.0282	0.0215
3	2.009	55.28	3.648	0.2017	0.1515	0.0568	0.0283	0.0216
3	2.004	56.03	4.520	0.2533	0.1943	0.0626	0.0312	0.0238
4	2.010	56.38	0.132	0.0074	0.0059	0.0377	0.0188	0.0115
4	2.007	55.35	1.448	0.0801	0.0603	0.0624	0.0311	0.0190
4	2.013	56.64	2.648	0.1500	0.1126	0.0697	0.0346	0.0211
4	2.004	56.40	3.400	0.1918	0.1449	0.0733	0.0366	0.0223
4	2.020	54.26	4.372	0.2372	0.1867	0.0863	0.0427	0.0260

TABLE VI

Langmuir and Freundlich Constants Used to Express Experimental Data

Acid	Carbon	Type Curve	Langmuir Constants a	b	Freundlich Constants k	n
Stearic	1	Langmuir	3.33	0.0120	-	-
Stearic	2	Langmuir	4.33	0.0105	-	-
Stearic	3	Langmuir	3.10	0.0275	-	-
Stearic	4	Langmuir	3.10	0.0275	-	-
Oleic	1	Langmuir	2.22	0.0145	-	-
Oleic	2	Langmuir	2.70	0.0115	-	-
Oleic	3	Freundlich	-	-	0.0126	3.97
Oleic	4	Freundlich	-	-	0.0126	3.97
Linoleic	1	Freundlich	-	-	0.0152	4.58
Linoleic	2	Freundlich	-	-	0.0100	7.26
Linoleic	3	Freundlich	-	-	0.0152	4.58
Linoleic	4	Freundlich	-	-	0.0152	4.58

Fig. I

Adsorption Isotherms
Stearic Acid adsorbed
on Carbon Black at 30°C.

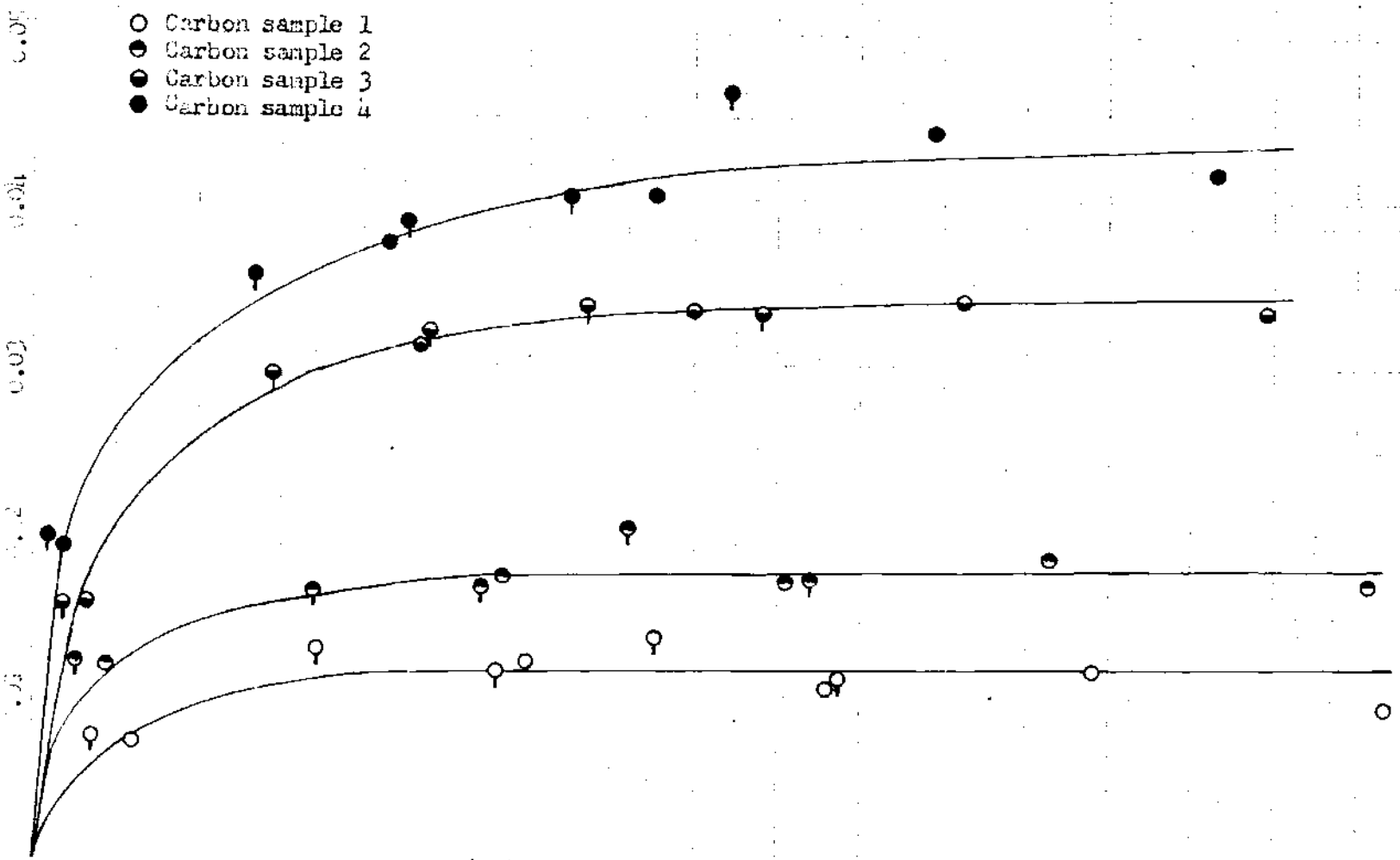


Fig. II

Adsorption Isotherms
Oleic Acid adsorbed
on Carbon Black at 30°C.

○ Carbon sample 1
◒ Carbon sample 2
◒ Carbon sample 3
● Carbon sample 4

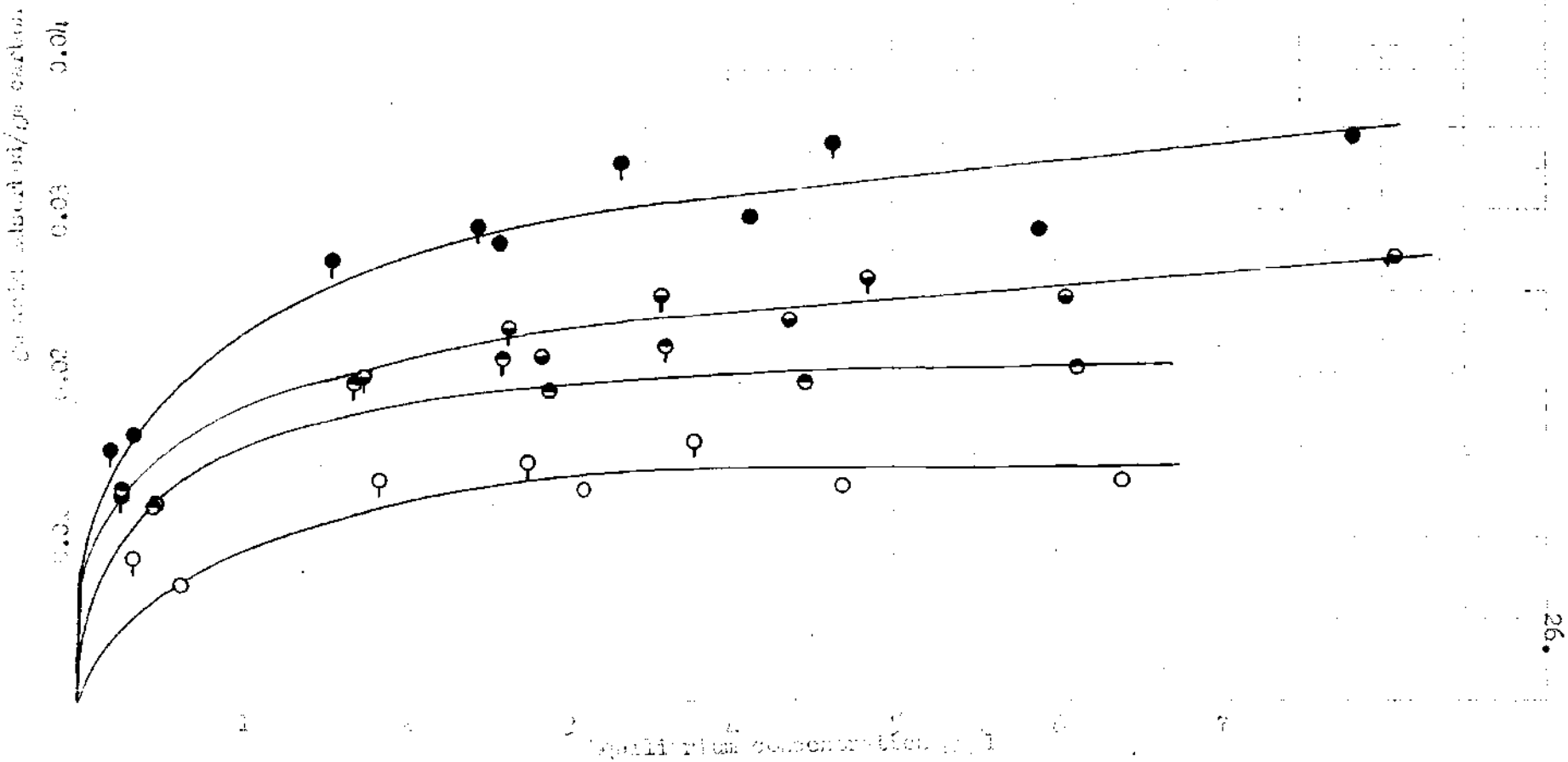


Fig. VII

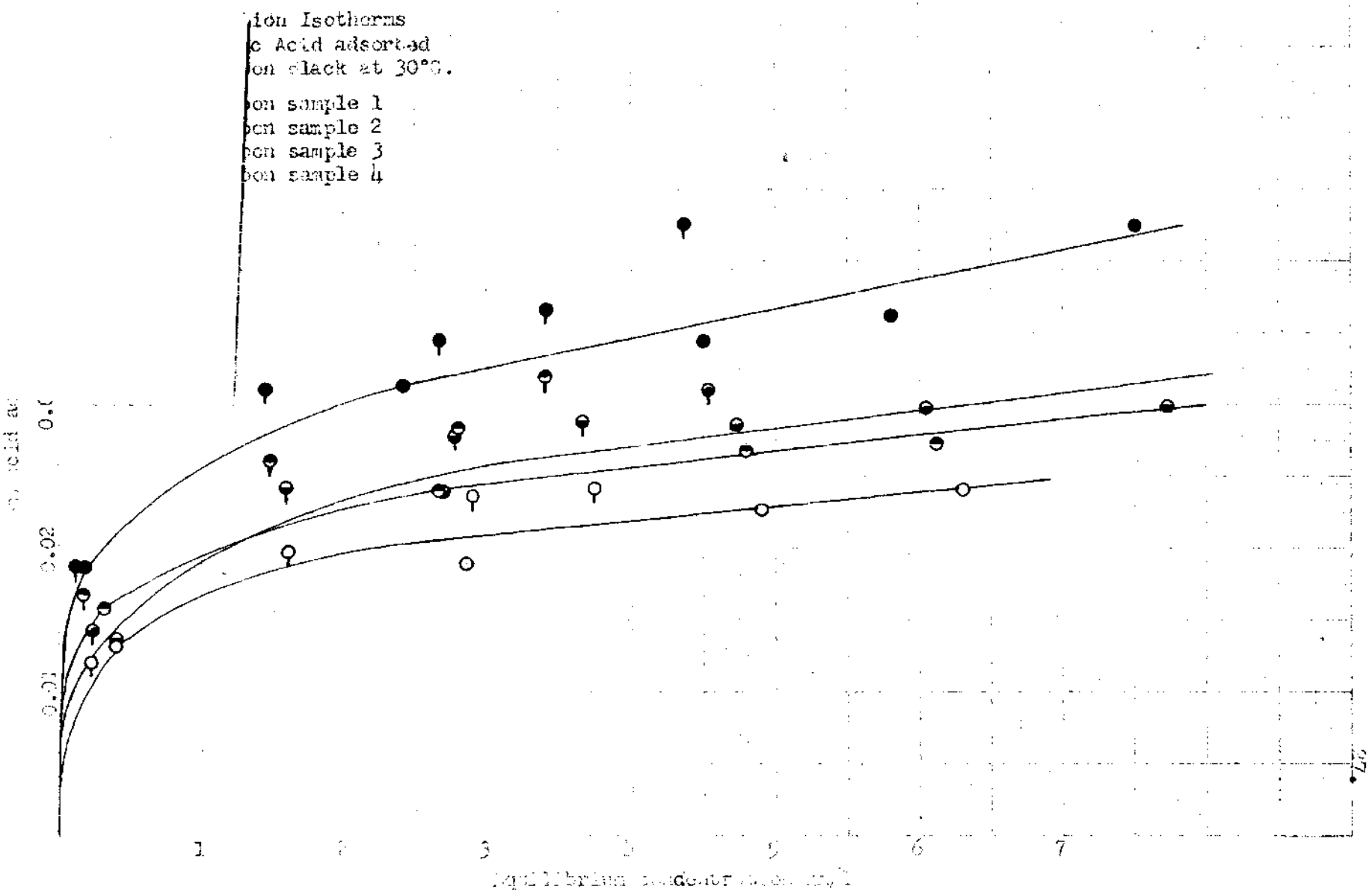

ion Isotherms
c Acid adsorbed
on black at 30°C.
on sample 1
on sample 2
on sample 3
on sample 4
0.02
1
3
7

Fig. IV

Adsorption Isotherms
Stearic Acid adsorbed
on Carbon Black at 30°C.

- ○ Carbon sample 1
- ◒ Carbon sample 2
- ◒ Carbon sample 3
- ● Carbon sample 4

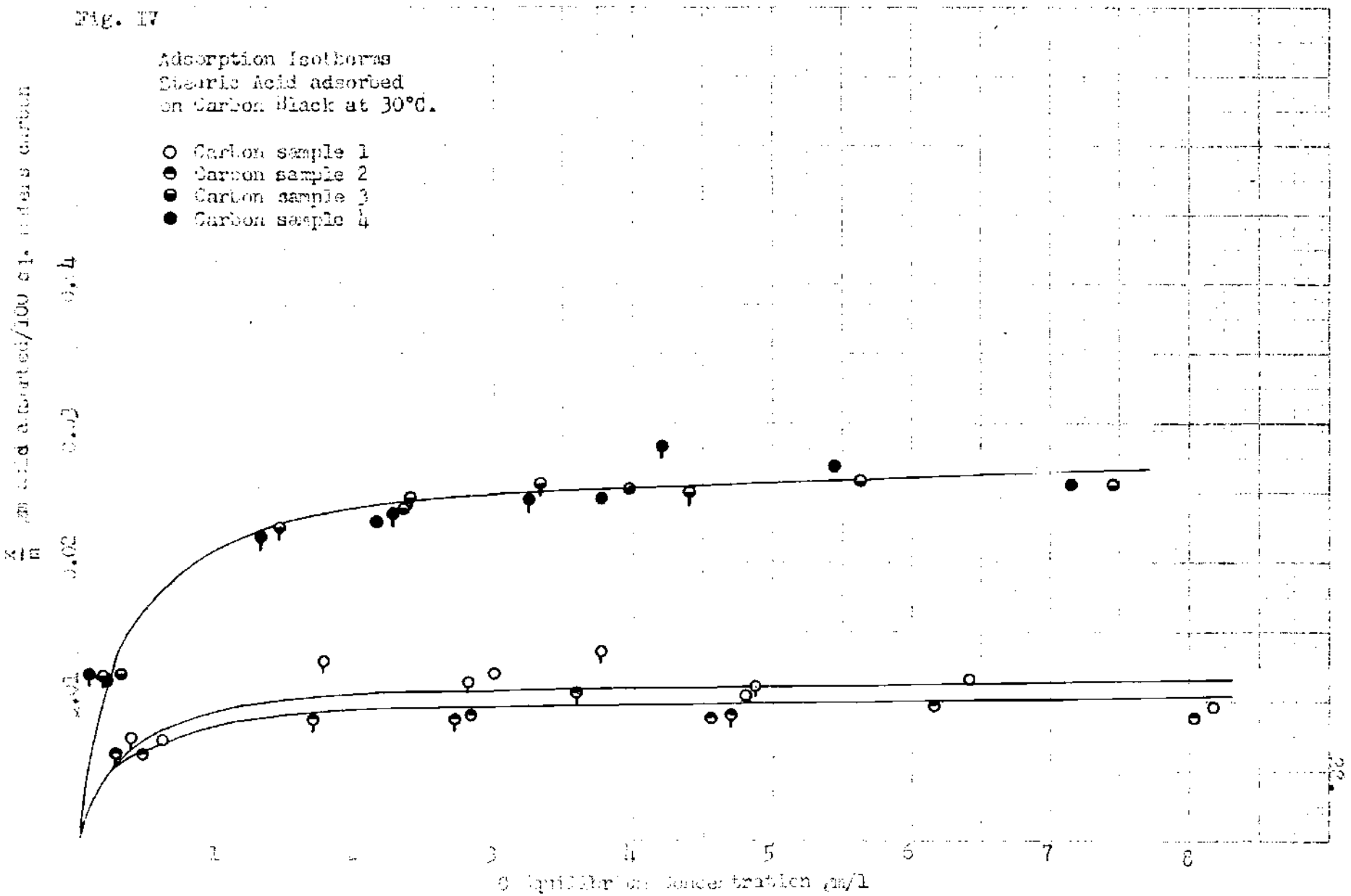


Fig. V

Adsorption Isotherms
Oleic Acid adsorbed
on Carbon Black at 30°C.

- ○ Carbon sample 1
- ◓ Carbon sample 2
- ◒ Carbon sample 3
- ● Carbon sample 4

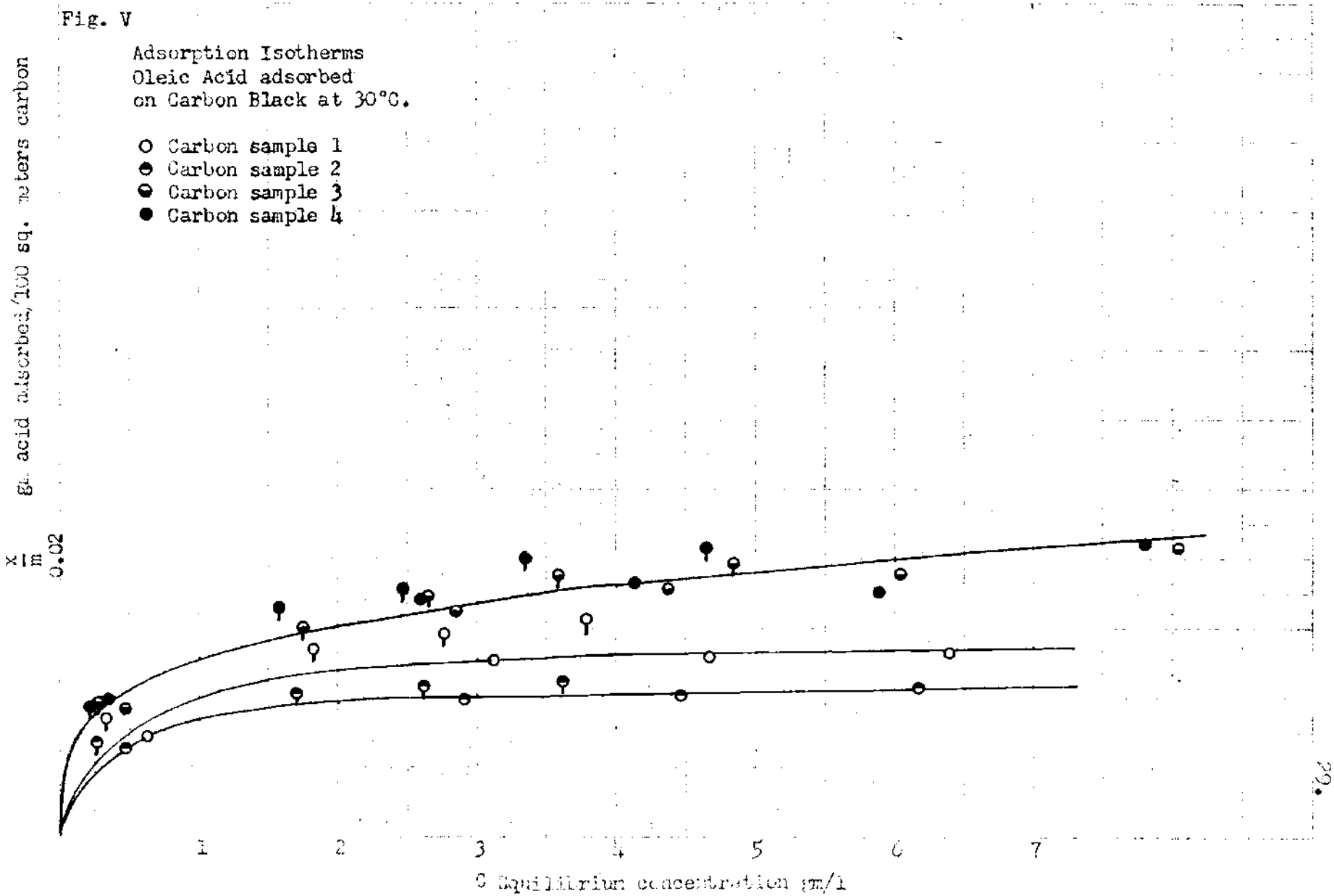
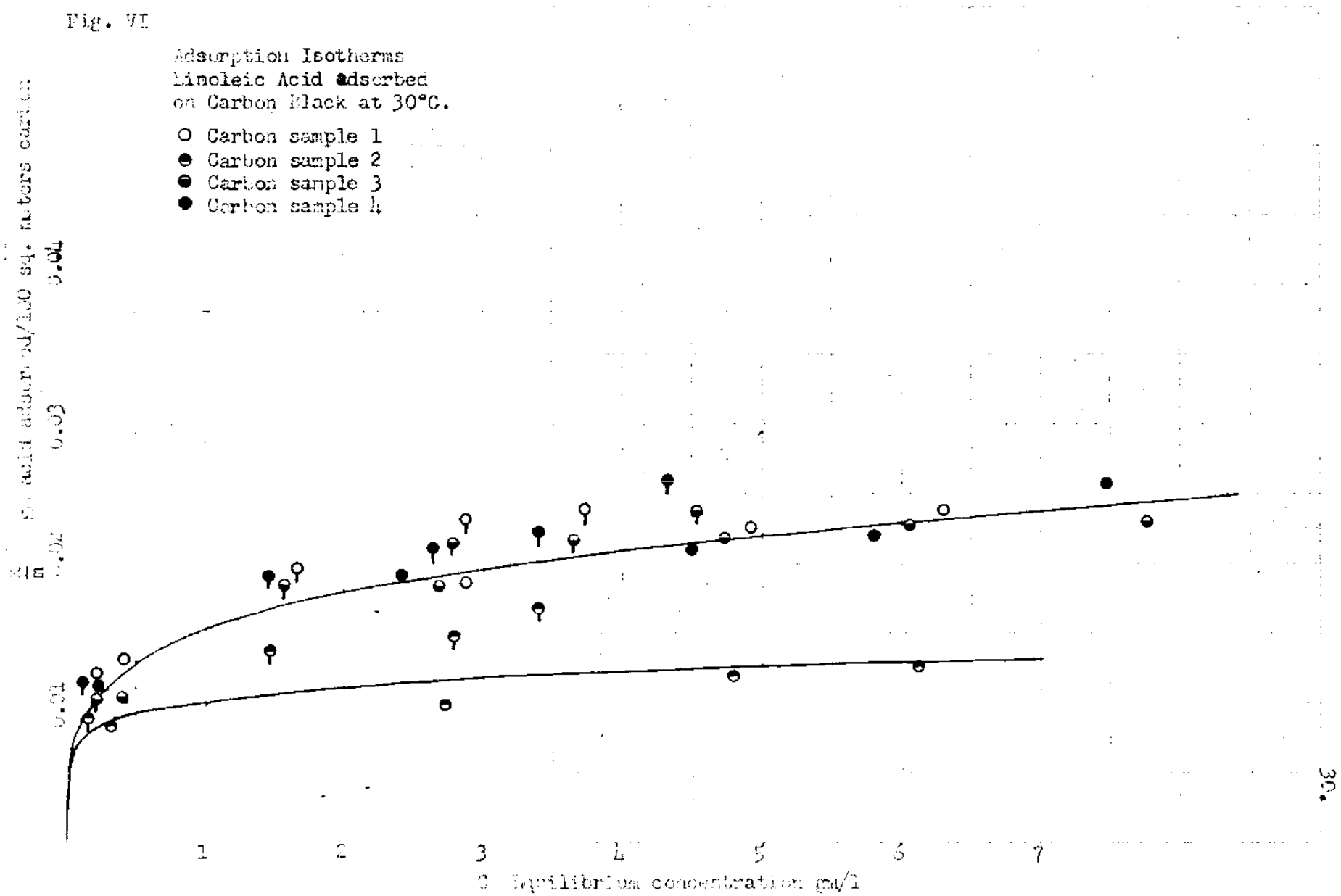


Fig. VI


Adsorption Isotherms
Linoleic Acid adsorbed
on Carbon Black at 30°C.
Carbon sample 1
Carbon sample 2
Carbon sample 3
Carbon sample 4
0.04
0.03
0.02
0.01
1
2
3
4
5
6
7
C Equilibrium concentration gm/l

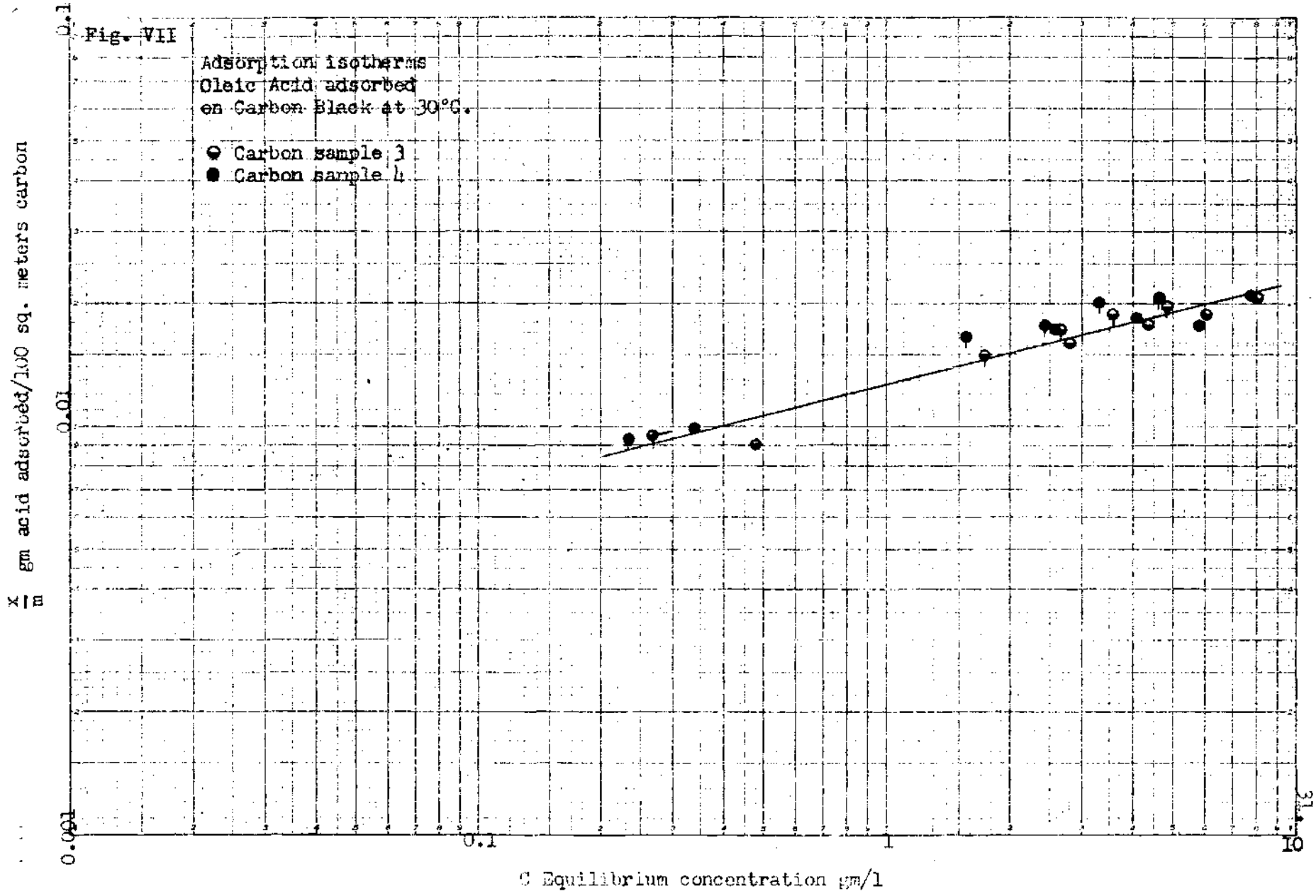
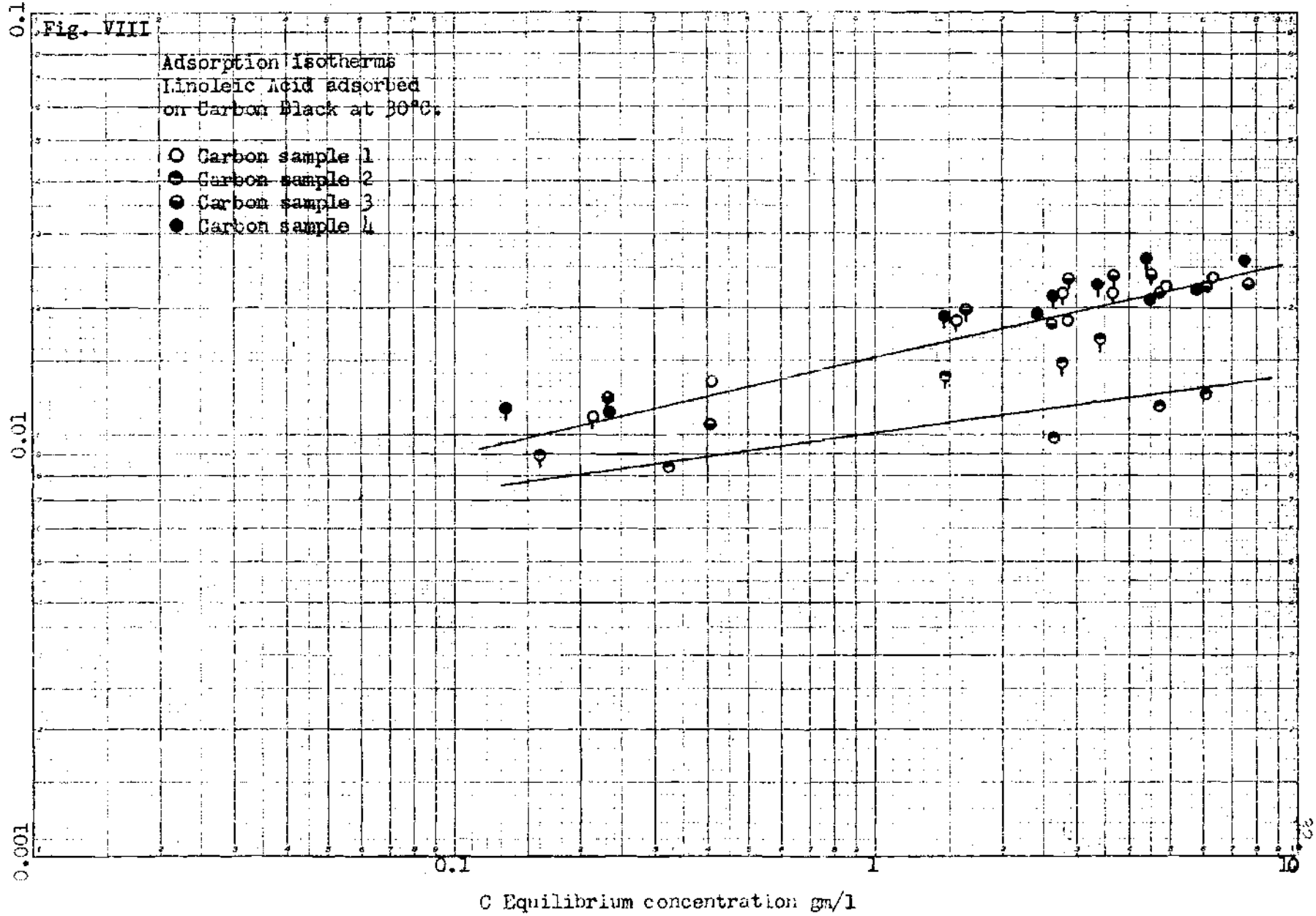


Fig. VII
Adsorption isotherms
Oleic Acid adsorbed
on Carbon Black at 30°C.
Carbon sample 3
Carbon sample 4
x/m gm acid adsorbed/100 sq. meters carbon
0.1
0.01
0.001
0.1
1
10
C Equilibrium concentration gm/l

Fig. VIII



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